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TRANSMUTATION OF RADIOACTIVE WASTE: EFFECT ON THE NUCLEAR FUEL CYCLE

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Abstract

A committee of the National Research Council reviewed three concepts for transmuting radionuclides recovered from the chemical reprocessing of commercial light-water-reactor (LWR) fuel: LWR transmutation reactors fueled with recycled actinides, advanced liquid-metal reactors (ALMRs), and accelerator-driven subcritical reactors for transmutation of waste (ATW). The concepts were evaluated in terms of: (1) the extent to which waste disposal would benefit from transmutation, (2) time required to reduce the total inventory of radionuclides in the waste and fuel cycle, (3) the complexity of the overall transmutation system, (4) the extent of new development required, and (5) institutional and economic problems of operating such systems. Transmutation could affect geologic disposal of waste by reducing the inventory of transuranics (TRUs), fission products, and other radionuclides in the waste. Reducing the inventory of transuranics does not necessarily affect radiation doses to people who use contaminated ground water if the dissolution rate of transuranics in waste is controlled by elemental solubilities. However, reducing inventories of Am and Pu would decrease potential hazards from human intrusion. The likelihood for underground nuclear criticality would also be reduced. The long-lived fission products Tc-99, I-129, Cs-135 and others typically contribute most to the long-term radiation doses to future populations who use contaminated water from the repository. Their transmutation requires thermal or epithermal neutrons, readily available in LWR and ATW transmutors. ALMR and LWR transmutors would require several hundred years to reduce the total transuranic inventory by even a factor of 10 at constant electric power, and thousands of years for a hundred-fold reduction. For the same electrical power, the ATW could reduce total transuranic inventory about tenfold more rapidly, because of its very high thermal-neutron flux. However, extremely low process losses would be reguired for the ATW.

1. TRANSMUTATION CONCEPTS

1.1. Concepts reviewed

The National Research Council committee reviewed three principal concepts for transmuting radionuclides recovered from spent fuel discharged from commercial light-water reactors (LWRs). The transmutation concepts were proposed in the U.S. for the purpose of simplifying the disposal of high-level waste. The three principal concepts were LWR reactors to transmute transuranics and fission products; advanced liquid-metal fast-spectrum reactors (ALMRs) proposed by the U.S. Department of Energy (DOE) to transmute transuranics; and fluid-fuel accelerator-driven subcritical reactors (ATWs) proposed by the Los Alamos National Laboratory (LANL) to transmute transuranics and fission products. Details are given in the committee's report [1]. Both DOE and LANL expected that their proposed concepts would significantly reduce the time required to isolate the remaining high-level waste from the environment. Each concept was accompanied by proposed new chemical processing for high-yield recovery and recycle of radionuclides to be transmuted, including on-line reprocessing of the ATW fluid fuels.

Each of these three transmutation concepts has been proposed as an alternative means of generating commercial electrical energy while reducing the amount of radionuclides that go to waste disposal.

1.2. Time to reduce the Transuranic (TRU) inventory

ALMR proponents speak of reducing the transuranic content of wastes by factors of 1,000 or greater, compared to the transuranics in unreprocessed spent fuel of the same electrical energy generation. ATW designers propose an even larger reduction in inventories of transuranics and key fission products, so that the remaining wastes would need to be isolated for "no more than a human lifetime."

In each of the concepts only a small fraction of the radionuclides charged to the transmutor is actually consumed during an irradiation cycle. Thus, the radionuclides recovered from transmutor discharge fuel must be recovered and recycled many times. Only a partial net reduction occurs during each reactor lifetime, the untransmuted radionuclides being passed to the next generation of reactors for further reduction. This is particularly true for the LWR and ALMR transmutors, although more rapid transmutation could theoretically be accomplished in the high-flux fluid-fuel ATWs.

During the long time for transmutation much of the radionuclide inventory will still appear in the reactor and fuel cycle. There can be no assurance that nuclear energy generation by reactors, including transmutor reactors, would continue for such long times or that similar transmutor reactors would be chosen to continue transmuting inventory remaining from previous transmutors. Therefore, the inventory of untransmuted radioactivity in the reactor and fuel cycle must also be considered as a potential waste.

The committee adopted as a performance index the ratio of accumulated radionuclide inventory in a reference LWR fuel cycle, operating without recycle and transmutation, to the inventory in a transmutation fuel cycle of the same electrical power. This ratio increases with time. Transmutation of total transuranics was emphasized in the transmutor concepts, so calculations were made of the transuranic ratio, a measure of the net inventory reduction of transuranics relative to the accumulated transuranic inventory produced by the reference once-through LWR. For an ALMR with a conversion ratio of 0.65 (a conversion ratio sufficiently high to preserve passive safety features and low enough to reduce the rate of production of new transuranics), and for 0.001 percent of the processed TRU appearing in the waste, several hundred years would be required to reduce the total transuranic inventory by even a factor of 10 at constant power. Thousands of years would be required for a hundred-fold reduction. Neither would meet the inventory reduction goal claimed for ALMR transmutation. The asymptotic transmutation ratio reached at longer times is less than the reciprocal of the fraction of transuranics processed that is lost to waste, because on average transuranics must be recycled many times through the reactor and reprocessing.

A LWR transmutor, with high-recovery reprocessing and transuranic recycle of mixed-oxide (MOx) fuel, would have a transmutation time constant similar to that predicted for the ALMR. However, transmutation with the thermal neutrons of an LWR would produce greater quantities of higher-mass transuranics than the ALMR and may require U-235 addition to achieve criticality at steady-state recycle. LWR transmutors could also transmute the long-lived Tc-99 and I-129 fission products that are predicted to be significant contributors to long-term radiation doses from geologic disposal.

The nonaqueous fluid-fuel ATWs would achieve much higher transuranic ratios in a given time, because of the extremely high thermal-neutron flux ($2 \times 10^{15}/\text{cm}^2\text{sec}$) claimed for the concept. Only about 7 years of steady-power operation would be required for a transuranic ratio of 10 and 40 years for a ratio of 100. The troublesome long-lived fission products Tc-99, I-129, and Cs-135 would also be transmuted. However, far greater transmutation ratios and longer times would be required to achieve the LANL goals for the ATW. The calculated transmutation performance must be balanced against the formidable problems of operating at the high required power density, as well as the practicality of the very complex on-line reprocessing system designed to achieve extremely low process-losses.

If nuclear power is assumed to phase out more rapidly, instead of operating at constant power for centuries assumed above, transmutors could be reduced in number and in total power as the total transuranic inventory now expected from the current U.S. LWRs is consumed. Such a declining-power scenario would achieve more rapid reduction in the radionuclide inventory, but the times required for the significant reductions by LWR and ALMR transmutors would remain long. For example, ALMR transmutors could achieve a TRU inventory ratio of 11 in 100 years, as compared to about 7 for constant power. Two centuries would be required to obtain a TRU ratio of 100, still tenfold lower than that desired by the ALMR designers.

1.3. State of technology and safety of LWR transmutor systems

The LWR is the most mature concept for transmuting transuranics and fission products. It relies on well-established technology for low-enriched uranium-dioxide fuel. Safety problems associated with recycle of transuranic fuel would have to be resolved. These include control-rod effectiveness and reactivity control, as well as safety of a new system for high-recovery reprocessing and fabrication of transuranics of much higher alpha and neutron activity than would exist in the ALMR transmutation fuel cycle. Plutonium recovered from first-cycle UO_2 is being recycled once as LWR MOx fuel in France and other countries. Far more technical problems are expected for multiple recycle of recovered transuranics as LWR MOx fuel. Multiple recycle would be necessary to destroy appreciable quantities of transuranics that would otherwise appear in radioactive waste.

There are no U.S. facilities for fabricating commercial mixed-oxide fuel or for reprocessing uranium fuel discharged from LWRs. Separations and target materials for fission-product transmutation would need development. New high-recovery processes would have to be developed, as well as new systems for reprocessing and fabricating multiple recycled transuranics in MOx fuel. These fuel-cycle facilities would require major technological development. Because of the estimated high cost of fuel reprocessing and fabricating recycle MOx fuel in new U.S. facilities, there are no clear financial incentives for commercial development of such facilities in the U.S., now or probably for many decades in the future.

1.4. State of technology and safety of ALMR transmutor systems

The ALMR transmutor would rely heavily on fast-breeder liquid-metal technology already developed in the U.S. and abroad. Designs with conversion ratios well below 0.65 would accelerate transmutation but would introduce new safety concerns associated with positive sodium-void coefficients. New safety issues will arise from reactor fuel containing Np-237 and other multiple recycled transuranics and fission products.

Existing PUREX separation technology, together with TRUEX for higher recovery, could be used to recover transuranics from LWR discharge fuel for transmutation in ALMRs. However, DOE's proposed new pyrometallurgical separation for uranium-dioxide fuel would require major development. Whether aqueous or pyrometallurgical processing is used, the required throughput of 2,700 Mg/yr of LWR spent fuel would far exceed the capacity of any commercial plant built in the U.S. or abroad. The pilot plant demonstrations of pyrometallurgical reprocessing EBR-II fuel would not be sufficient to establish the technology and to resolve licensing issues of reprocessing LWR fuel and reprocessing and fabricating multiply recycled transuranic fuel from an ALMR transmutor. Remote maintenance and process control are key problems that must be resolved in designing a licensed industrial-scale facility. Extensive tests to qualify the new waste forms for geologic disposal would be necessary.

1.5. State of technology and safety of ATW transmutor systems

The ATW is a subcritical assembly of $k_{eff} = 0.95$, driven by a neutron-producing high-current accelerator. Most of the transmutations occur from reactor-produced neutrons. LANL states that the main benefit from the accelerator would be to avoid safety issues of critical reactors. No control absorbers are to be provided. However, a high-flux fluid-fuel reactor such as the ATW is likely to be subject to greater reactivity swings than can be controlled by an accelerator designed for $k_{eff} = 0.95$. Also, because most of the energy produced is from fission, the ATW would be subject to problems of emergency removal of fission-product decay heat, made severe by the extremely high power density.

In the event of a loss of coolant flow, the ATW fluid fuel must be promptly cooled to prevent overheating and to prevent volatilization of many of the radioactive species that are already in a mobile form in the fluid fuel. The ATW design has not confronted the pipe-break criterion adopted for reactor licensing. The molten-salt ATW would introduce additional safety problems such as containment of the molten-salt fuel, possible xenon instability at high thermal flux, xenon interaction with graphite moderator, and shutdown by Sm-149 following power fluctuations. Fluid-fuel boundary-layer heating, a crucial problem in earlier fluid-fuel reactors, will be more severe at the high thermal flux. Also, because of the high thermal flux, the production of americium and curium will be far greater than in the ALMR and LWR transmutors. The high alpha and neutron activities will add to the large radioactivities of fission products in the fluid fuel and the integrated reprocessing systems. Loss of integrity of the spallation target and its cooling system, especially in the high-flux region, could be detrimental to reactor safety. The safety problems of the ATW concepts are expected to be far more severe than for the ALMR and LWR transmutors.

All reprocessing operations proposed for the ATW are new and unproven. Instead of relying on aqueous reprocessing to recover transmutable transuranics and fission products from LWR spent fuel, LANL proposes to develop a new nonaqueous fluoride volatility process with extremely low process losses to waste. Several separate nonaqueous on-line chemical separations are also planned: (1) continuous reprocessing of spallation targets to recycle radioactive spallation products for transmutation, (2) cascades of ultracentrifuges, operating on molecular-weight differences of solutes, to separate transuranics and fission products from the molten fluoride salt and from each other, and (3) isotopic separation of Cs-135, in the presence of highly radioactive Cs-137, to form pure Cs-135 targets for transmutation. The required process losses per cycle through the on-line separation units are extremely low, less than 2 x 10^{-4} per cycle for plutonium and neptunium and 3 x 10^{-6} for americium and curium. Even the basic technical feasibility of such processing in the intense radiation fields is subject to question.

LANL has not sufficiently addressed the issues of whether greater reliability and safety, as well as more economical operation, could be obtained with a critical reactor of similar design but not incorporating the neutron-producing accelerator. Make-up U-235 could be added if additional neutrons are needed for transmutation.

2. SEPARATIONS REQUIRED FOR TRANSMUTATION

For separation and transmutation of actinides, some form of aqueous separations involving a combination of PUREX and TRUEX solvent extraction processes could be used with any of the transmutation concepts. Although PUREX usually produces separated streams of uranium and plutonium, as well as high-level waste containing fission products and transplutonics, a PUREX modification is available to produce separated neptunium as well. However, the PUREX recovery fractions are not large enough to produce the degree of transuranic recovery desired by transmutation proponents. TRUEX would be added for high recovery and recycle of transuranics. TRUEX utilizes organophosphates such as carbamoylmethylphosphineoxide (CMPO). TRUEX may also be adaptable to extracting and separating the heptavalent technetium fission product. Additional research and development would be required before full plant-scale use of the TRUEX technology. The high-level-waste form for geologic disposal would be borosilicate glass. Additional TRU waste and low-level waste would be generated.

Transmutation of long-lived fission products would require development of additional separations to be added to PUREX. TRUEX using CMPO extractant could removed technetium from acidic fuel solution. Processes are already available to separate carbon-14, radioiodine, and cesium, but improvements in recovery efficiency may be needed.

The Argonne National Laboratory (ANL) advocates the Integral Fast Reactor (IFR) fuel separation process, both for processing ALMR metallic fuel for recycle and for processing LWR spent fuel to recover and recycle transuranics for transmutation in ALMRs. ANL believes that such reprocessing facilities of small capacity and integral to individual ALMRs could be economical. The IFR process is based on the selective electrorefining of uranium, plutonium, and other actinides from a molten cadmium solvent (the anode), into which they have been dissolved by anodic dissolution of spent IFR or LWR fuel. The IFR process is designed to separate the transuranic actinides as a group and does not produce an essentially pure plutonium stream. Rare earth fission products are recycled along with the transuranics. Other fission products collect at the anode. New waste forms are generated and must be extensively tested to qualify for geologic dispoal. There are many sources of secondary waste that must be dealt with.

The IFR reprocessing system would consist of a large number of compact, criticality-limited electrorefiners operating in parallel to obtain suitable throughput. Each must be operated batchwise, as contrasted to the continuous operation of the PUREX system. Process control and maintenance are key issues. The IFR reprocessing system would need considerable development and testing before it could be considered suitable for commercial operation. Application of the pyrometallurgical process to LWR spent fuel has been proposed but is far from pilot-scale demonstration. The practicability of integrated reprocessing at commercial nuclear power plants is questionable.

The Los Alamos National Laboratory proposed two entirely different fluid-fuel ATW reactors to transmute fission products and transuranics, one based on a high-pressure slurry of transuranics in heavy water and another based on a fused-salt solution of transuranics and fission products. Los Alamos has since focused on the fused-salt system described herein. The molten salt consists of Li^7-Bi-Th fluorides, with a melting point above 500°C, containing transuranics and fission products. The molten salt circulates through heat exchangers to boil water and generate electrical power. The principal design feature of the ATW is operation at very high neutron flux to reduce the time required for a given percentage conversion of transmutable species. This requires high specific thermal power (thermal power from fission per unit mass of fissile species in the entire transmutation system[1]). To minimize the fissile inventory that would otherwise exist in a separate reprocessing system, the ATW design proposes on-line reprocessing.

The ATW on-line separation system must be resistant to the enormous alpha and neutron activities, exacerbated because the transuranics in the circulating fuel will be mainly americium, curium, and even higher-mass transplutonic species. The variety of nonaqueous separations, including fluoride volatility and molten salt processes, now under study, pose challenging problems of corrosion and containment. The required separation factors are extremely high[2], far beyond any yet demonstrated. LANL proposes to develop high-temperature ultracentrifuges that operate on molecular-weight differences of solutes in the molten salt. To transmute Cs-135 it will be necessary to separate Cs-135 from the other cesium isotopes formed in fission, to avoid further generation of Cs-135 by neutron capture in stable cesium. Separating these isotopes in the presence of the enormously high activity of Cs-137 would be a formidable problem, never before encountered in isotope separation. The ATW separations concepts are at such a preliminary stage of study that any judgment on their technical viability is premature.

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[1] The ATW is designed to be accelerator driven with $k_{eff} = 0.95$. Most of the neutrons for transmutation come from fission of transuranics. High specific power based on fissile material ensures high neutron flux for transmutation, as it does in critical systems.

[2] Maximum allowable process losses, to achieve the design goals, are 0.02 percent for plutonium and neptunium and 0.0003 percent for americium and curium, for both on-line separations of the fused-salt mixture as well as for the separate reprocessing of LWR spent fuel.

3. IMPACTS ON WASTE DISPOSAL

3.1. The need for an adequate measure of performance

All of the proposed systems for transmuting radionuclides present in LWR spent fuel have the potential to affect the design and long-term performance of disposal systems for spent fuel and other radioactive waste. The waste going to geologic repositories would contain reduced quantities of several radionuclides and would generate less thermal power. It would be in forms different from spent fuel, with the potential of designing waste forms tailored more to the demands for stability and slow release in a geological environment. Even reprocessing without recycle and transmutation could accomplish the latter. The claims of possible benefits to geological disposal have ranged from eliminating the need for a U.S. geological repository to providing a sounder technical basis for licensing. Another claimed benefit is that reducing the decay heat rate of the waste would permit a given repository site to store waste from a greater amount of electrical energy generation, thereby eliminating or postponing the need for a second repository.

Unfortunately, the many claims of benefits to waste disposal have not been scientifically based. Claims of reduced hazard from radioactivity have relied on toxicity calculations that compare the toxicity of spent fuel to that of uranium ore. Toxicity at any future time is calculated from the inventory of radionuclides weighted by the biological effectiveness of each radionuclide if assimilated into the human body. It does not indicate even the relative hazard, because it takes no account of the probability that a radionuclide in a disposal system will eventually escape and reach the environment. Also, comparison with uranium ore is not a valid measure to determine what might be an acceptable reduction of the amounts of radionuclides in waste [2].

A valid performance assessment of a radioactive waste repository must evaluate possible future conditions and events that might allow radioactivity to be released to the environment and cause radiation doses to future populations. Two general areas are typically addressed: (1) transport of radioactivity from the waste solid, through geologic media, into the human environment, and (2) disruptive events and inadvertent human intrusion that could cause a portion of the repository contents to be directly transported to the surface or injected into flowing ground water.

3.2. Radiation doses from hydrogeologic transport

Calculations made to date show that doses to future individuals may result mainly from long-lived radionuclides. The most important in ground-water pathways are typically the long-lived fission products Tc-99, Cs-135, and I-129. None of these are important contributors to waste toxicity. For a repository in unsaturated rock, such as the proposed Yucca Mountain site in the U.S., Np-237 may also contribute importantly to long-term doses from hydrogeologic transport [3]. Pa-231 and Ra-226, decay-daughters of the long-lived U-235 and U-238 in waste, can also be important long-term contributors. To the extent that long-term doses from these species are threats to public health, reprocessing spent fuel would create the opportunity to sequester each of these species (or their parents) into more durable low-solubility waste forms.

Recycle of separated transuranics for transmutation would accomplish little in terms of reducing long-term dose, except possibly for Np-237 in an unsaturated repository. To reduce long-term doses by transmuting Tc-99, Cs-135, and I-129, thermal or epithermal neutrons are needed, as could be available in LWR and ATW transmutors. However, if low-solubility waste forms of the important radionuclides are available, reducing the inventory of these radionuclides by a few factors of ten or so does not necessarily affect the peak doses, as long as enough of each species is present to saturate the aqueous film that eventually contacts the waste form containing that species. In fact, the proposal to increase the repository capacity by transmuting heat-generating transuranics and to decrease the inventory of Np-237 by transmutation could increase the number of waste containers and actually increase the long-term dose from Np-237. Even if Np-237 inventory is not reduced by transmutation, sequestering the Np-237 into a separate and more stable waste form of lower solubility can result in lower long-term radiation dose.

3.3. Radiation doses from intervention

Future human intrusion into a repository, as by exploratory drilling or for other reasons, and disruptive events, such as earthquakes, meteorite impact, magma intrusion, can cause a portion of the repository contents to be directly transported to the surface or injected into flowing ground water. These events can occur early in life of the repository, as well as at later times, and they could extract radioactivity directly from the waste package. Here plutonium and americium isotopes could be main contributors to hazards. Such events have been analyzed for the Waste Isolation Pilot Plant (WIPP) in New Mexico, U.S. Consideration of human intrusion intersecting a single waste package at Yucca Mountain has been proposed. However, regulatory requirements based on protecting public health from such intervention are not yet defined. If exposure of future humans directly to the contents of a waste package at any time after repository loading is to be considered, external exposures from Cs-137 and other fission products could be important. Internal exposures could be dominated by Sr-90, Cs-137 and plutonium and americium isotopes. Transmutation of transuranics, as proposed by the ALMR project, would seem to benefit repository performance in this regard after the more intense fission products have decayed. However, according to the time-dependent inventory reduction analysis of Section 2.2, a substantial portion of the transuranic inventory would still exist above ground in ALMR or LWR transmutors and associated reprocessing facilities for a few thousand years at steady power. Accidental or willful intervention of this enormous amount of radioactivity could be more hazardous than intervention into a repository containing spent fuel.

3.4. Reducing decay heat by transmutation

Elimination of all transuranics in repository waste would reduce heat generation relative to spent fuel. At ten years after discharge the transuranics in spent fuel contribute 20 percent of the heat generation by radioactive decay, 60 percent at 100 years and 99 percent at 300 years. If this reduction is coupled with sequential waste emplacement after transmuting the transuranics, the capacity of a given repository site, measured in terms of equivalent electrical energy generation, could be increased by about fivefold. However, it has been pointed out that the design capacity of Yucca Mountain is limited by political agreement, not by area. Also, techniques other than transmutation could increase the capacity of a given site, such as sequential loading of unreprocessed spent fuel of different ages.

4. GENERATION OF OTHER WASTE

In spite of claims by ALMR and ATW proponents, all transmutation systems reviewed here would yield products from reprocessing, maintenance, and decommissioning that would contain enough radioactivity to require disposal in a geologic repository. All transmutation systems would generate greater quantities of low-level and TRU waste than that for the once-through LWR fuel cycle.

5. INSTITUTIONAL AND ECONOMIC ISSUES

DOE and its contractors expect that transmutor systems will be adopted by the electrical utility industry as economic alternatives to once-through power-generating LWRs. LANL adds thorium to its ATW transuranic fuel to lower the fuel cost. However, choosing and deploying a transmutor system to simplify waste disposal would be far more complicated for a utility than merely selecting a new nuclear power plant. For example, to accomplish DOE's program goals for transmutation in the U.S., about 30 GWe generated from about 22 ALMR transmutors of 0.65 conversion ratio would be required. The 63,000 Mg of LWR discharge fuel, now destined for Yucca Mountain, would be reprocessed to supply transuranics to start the ALMR transmutors and to supply make-up transuranics during their operating life.

The many different utility owners would have to agree to construct and operate not only the first-generation transmutors but also the many generations of replacement transmutors until the desired reduction in transuranic inventory is achieved. Each of these ALMR transmutors would have its own integrated pyrometallurgical reprocessing plant, at a scale generally considered too small for economical reprocessing, a kind of operation not heretofore experienced in the utility industry. Even before any first-generation transmutors were built, new facilities to reprocess LWR spent fuel would have to be constructed, with a total capacity of 2,700 Mg/year and with an entirely new chemical process. The total capacity would exceed that of any commercial reprocessing facility yet constructed. To accomplish the transmutation schedule proposed by DOE's contractors, the above commitments must be in hand within the next few years.

The costs of development of any of the transmutation concepts would be large, but the financial risks of such large commitments are even more formidable. Cost estimates from the transmutor programs do not seem reliable, particularly in the area of reprocessing. DOE contractors' recent cost estimates for even conventional aqueous reprocessing are over fourfold lower than recent costs for contemporary facilities in other countries. Extrapolating those contemporary costs to a reprocessing facility in the U.S., and with no allowance for additional costs for high-yield recovery and multiple recycle, we estimate that the cost of U.S. reprocessing the 63,000 Mg of U.S. LWR spent fuel, based on costs of contemporary facilities and optimistically neglecting the necessary additions for high-recovery separations, would be $133 billion for commercial ownership, or $51 billion for government ownership, far greater than the presently expected cost of the geologic disposal program. We estimate a large additional cost for fabricating MOx fuel. It is likely that the new technological features and problems associated with deploying any of the transmutation concepts, as outlined above, would add even more to the total cost. Only a small fraction of this reprocessing/fabrication cost could be offset by reducing the amount of make-up uranium fuel below that required to fuel once-through LWRs. Claims by ALMR transmutor proponents that new pyrometallurgical high-recovery reprocessing techniques would reprocess LWR fuel at far lower cost, sixfold less than what we estimate for costs of contemporary aqueous reprocessing plants, are yet to be proven.

To be an appreciable benefit to waste disposal, any transmutation plan must be initiated and operated as an integrated total system. It does little good to build transmutors without suitable facilities for reprocessing and fuel fabrication. Siting and transportation issues must be faced for the entire transmutation system. These problems of system integration have not been faced by transmutation proponents; they are particularly formidable in the present climate in the U.S.

It would take massive commitments and guarantees by the federal government to ensure the success of such a large and complicated project even on a more relaxed schedule than would be required to transmute the U.S. spent fuel now destined for geologic disposal. It seems prudent instead to do the technical work necessary to ensure the success of geologic disposal of spent fuel. Some modest focused effort on transmutation systems is warranted, particularly on developing low-cost reprocessing, until it is learned whether geologic disposal needs and can profit by waste transmutation.

6. CONCLUSIONS

After considering the information summarized above, our committee reached the following conclusions about the feasibility of reprocessing and transmutation and the impact on the U.S. repository program:

1. Separation and transmutation (S&T) of transuranics and certain long-lived fission products in spent reactor fuel is technically feasible and could, in principle, provide benefits to radioactive waste disposal in a geologic repository. However, to begin to have a significant benefit for waste disposal, an entire S&T system consisting of many facilities would have to operate in a highly integrated manner for several decades to hundreds of years. The deployment of an S&T system that is extensive enough to have a significant effect on the disposition of the accumulated LWR spent fuel would require many tens to hundreds of billions of dollars and take several decades to implement.

2. The proposed S&T systems would require decades to centuries to achieve a significant net reduction in the total TRU inventory relative to that of a once-through LWR fuel cycle.

3. The S&T systems differ widely in their state of technological maturity and present a broad spectrum of development issues, risks, costs, and schedules. The most mature system concept for transmuting transuranics and fission products, based on the use of LWRs, needs fuel-cycle development and would require significant financial resources and enormous institutional commitment to reach the point of deployment. The ALMR/IFR system for transmuting transuranics would require even more financial resources and take longer to reach deployment. The ATW concepts would require major development before even the technical feasibility and chances of success can be realistically assessed.

4. There is no evidence that application of transmutation and its associated advanced reprocessing holds sufficient merit for the U.S. to delay the development of its first nuclear waste repository to contain commercial spent fuel. Even if a transmutation system were in place, a geologic repository would still be needed.

5. Application of reprocessing and transmutation does not hold sufficient merit to abandon the once-through fuel cycle in the U.S.

6. While the need for a second repository could be delayed by reprocessing and transmutation, there are several other ways, both legislative and technical, to increase the capacity of the first repository by a comparable amount.

7. RESEARCH AND DEVELOPMENT NEEDS

There is no immediate need for the U.S. to deploy any of these proposed technologies for separations and transmutation, primarily because there is no present indication that S&T is necessary for the repository program to meet its goals. The U.S. repository program is expected to be of long duration. The high cost of reprocessing and fabrication of recycle fuel is unfavorable in the current era of low-cost uranium and enrichment. Therefore, research and development on S&T cannot be viewed as urgent. For the near future in the U.S., S&T is best regarded as a contingency option. On the other hand, implementation of reprocessing/S&T could become desirable under a variety of situations. These could include a change in the economic viability of reprocessing and recycling in the U.S., new technical problems in meeting regulatory guidelines for a spent-fuel repository for geologic disposal, and the need for increased nuclear energy to ameliorate the climatic impacts of other energy production technologies. Therefore, it is desirable to sustain a modest level of research and development on S&T technology, with emphasis on its benefit to the repository program and on the development of efficient low-cost separation technologies.

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